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THE VISUAL EVOKED RESPONSE AS A MEASURE OF NITROGEN NARCOSIS IN NAVY DIVERS

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9015DA5G.02

Released by

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SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 664

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SUMMARY PAGE

PROBLEM

To assess the use of the visual evoked cortical response as a measure of nitrogen narcosis in Navy divers.

FINDINGS

The visual evoked responses of divers breathing air has revealed reliable and significant decrements at depth. These are attributable to the narcotic effects of nitrogen since no comparable losses were found at depth when the divers breathed helium-oxygen.

APPLICATION

Nitrogen narcosis presents a problem not only for divers of today, but for the design of future escape systems for submarines incapacitated at depth. The visual evoked response can be used to assess the range of individual differences and the extent of man's capabilities while operating at depth.

ADMINISTRATIVE INFORMATION

The investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9015DA5G - Vision Under the Stresses Found in Naval Diving and Submarine Environments. The present report is No. 2 on that Work Unit. It was approved for publication on 21 April 1971 and designated as Submarine Medical Research Laboratory Report No. 664.

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ABSTRACT

This study assesses the possible use of the visual evoked response as a measure of nitrogen narcosis in divers. Responses to a patterned visual target were recorded from the scalp over the occipital cortex, from divers breathing air in the NAVSUBMEDRSCHLAB's pressure chamber. Records were obtained at the surface, and at 100, 200, and 250 feet. Control dives to 250 ft with the same men breathing helium-oxygen were also performed. The results showed significant decreases in amplitude and regularity of the VER as a function of depth for divers breathing air but no comparable decrements with helium-oxygen.

THE VISUAL EVOKED RESPONSE AS A MEASURE OF NITROGEN NARCOSIS IN NAVY DIVERS

INTRODUCTION

One of the major achievements of research on diving physiology and hyperbaric pressure is the increased potential for escape from a disabled submarine. In the past, if a submarine could not surface on its own, there was no possibility of survival for the crew unless the submarine was in less than 100 feet of water. Escape capability has increased at least threefold in recent years and now the goal is a workable submarine escape system for anywhere on the continental shelf.

One of the many factors that must be considered in designing a system to achieve this goal is the degree of nitrogen narcosis that will be encountered. It is possible that the men attempting to escape might become so narcotic, breathing air at depth, that they would be incapable mentally of reaching the surface, even though technologically the escape system was effective.

This investigation is part of an overall attempt to find a sensitive and reliable measure of nitrogen narcosis in man, to determine the range of individual differences, and to establish the extent of man's capabilities while operating at depth on compressed air.

A vast number of indices have been utilized in the past, in an attempt to quantify the narcotic effects of nitrogen. Many of these, on a medical or physiological level, help to yield a basic understanding of the general effect.[1,2] Yet, as is pointed out by Jennings[3] in his recent review of the literature, nitrogen narcosis is basically a behavioral problem; that is, it is the subtle change in character and behavior that occurs and that can cause disasters at depth. While Jennings advocates a systematic series of behavioral indices to assess nitrogen narcosis, another approach has been attempted in this study.

Changes in the functioning of the central nervous system (CNS) are implicated in these narcotic effects, both on a theoretical level—in order to account for the changes in personality—and on the basis of empirical assessments of CNS functioning at depth.[4,5,6] Thus a direct measure of CNS function, such as the cortical evoked potential, may provide one of the earliest indications of oncoming narcosis. This would be preferred, if it succeeds, to attempting to sample all the different types of behavior of which man is capable to determine which are and are not susceptible to narcosis.

This study therefore was undertaken to determine if the visual evoked response (VER) may provide a sensitive and reliable measure of nitrogen narcosis by recording VER's from divers breathing compressed air in a pressure chamber simulating depths from zero to 250 feet.

APPARATUS AND METHOD

The visual evoked responses (VER's) were recorded from bipolar electrodes

located on the midline of the scalp 2 cm and 7 cm above the inion. A ground electrode was placed on the subject's ear. The potential from the electrodes was fed to a Grass P511 Pre-Amplifier which was set to amplify the signal at a nominal value of 50,000. The signal from the pre-amplifier was led both to a Tektronix oscilloscope, for on-line visual monitoring, and to a Technical Measurement Corporation's Computer of Average Transients (CAT) for summation. Data were read out from the CAT to a Plotomatic X, Y plotter. A preset sweep counter by TMC regulated the number of signals summated by the CAT.

The analysis interval, that is, the length of interval following a stimulus which is summated by the C.A.T., was one second. One hundred cortical responses of this one-second interval were summed.

The visual stimulus was a pattern of vertical stripes formed of opaque black paper and clear plastic. The striped pattern was attached to a porthole of the NAVSUBMEDRSCHLAB's pressure chamber. Subjects viewed the stripes from inside the chamber; the pattern was back-lighted by a Grass PS-2 Photostimulator located outside the chamber. At the subject's viewing distance of four feet, the striped field was a square subtending a visual angle of 5° on a side. Each stripe subtended 30 minutes in width.

The intensity setting on the Grass photostimulator was 16. This produced a luminance on the clear portion of the striped pattern of about 240 ft-L at 2 cps and 600 ft-L at 16 cps. Measurement was made by a visual match to a standard using the Luckiesh-Taylor brightness photometer. The duration of the flash is approximately 10 μsec.

Two different flash rates were employed to view the striped target: 2 flashes per second and 16/sec. The order of presentation of the two flash-rates was randomized.

Four qualified Navy divers served as subjects; these men had extensive experience in chamber dives. There were, in fact, performance data available on them: the results from tests of mental arithmetic, complex reaction times, and a letter cancellation task performed under the same hyperbaric conditions as this study.

PROCEDURE

Visual evoked responses were recorded at three depths, 100 ft, 200 ft, and 250 ft, while subjects breathed ordinary compressed air. Two divers participated in each experimental dive; each S made two dives to each depth.

In order to eliminate from consideration daily variations, in electrode emplacement, impedance, or the subject's sensitivity, control runs at the surface were made each day prior to the actual dive and repeated at the surface following the dive. The data therefore always consist of a comparison of VER's at depth with pre- and post-control VER's obtained in the same experimental session for each subject.

Following the control runs, the chamber was pressurized; the descent

took from one to four minutes depending on the depth; and the time on the bottom was approximately 12 minutes. During these twelve minutes, two VER's (at 2 and 16 cps) were recorded for each diver. Decompression followed an experimental schedule of 60 ft per minute with various decompression stops. There were none on the 100 ft ascent; the total decompression time from 200 ft was 38 minutes and from 250 ft, 67 minutes, 33 seconds.

During decompression from 250 ft, there was a stop for seven minutes at 70 ft. VER's for both subjects to one stimulus condition, the 16 cps rate, were recorded during this time as a further control. The time interval from leaving the bottom to arrival at this stop was 3 minutes.

CONTROL EXPERIMENTS

There are a number of physical conditions which differ between the surface and simulated dives to depth in a pressure chamber. Since any one of these conditions might contribute to changes in visual evoked responses, a number of control studies were run to assess the importance of the individual factors.

(1) When the chamber is pressurized the temperature increases markedly; it may rise as high as 39°C for the 250-ft dive. Since such temperature variations might change the conductivity of the subject's skin or the electrode impedance, VER's were recorded in a sauna operated at 37-39°C. All other conditions remained the same as in the pressure chamber.

(2) The noise of the compressed air entering the chamber during compression is excessive, the level in the chamber commonly reaching 110 dB during a descent at 60 ft/min. A dive to 10 ft, followed by extensive venting of the chamber, provided a noise control for the deep dives without the depth.

(3) An empirical assessment of time, <u>per se</u>, was made since some of the post-surface control VER's were recorded considerably later in time due to lengthy decompression schedules. VER's were recorded, in the pressure chamber, at the surface on all of the divers at varying time intervals up to 1-1/2 hours after the first record was made.

(4) Finally, the 250 ft dives were repeated, on two different occasions for each diver, with the breathing mixture changed to helium-oxygen. This control allows a direct assessment of the effect of nitrogen since everything else remains the same except for the gas. Standard Navy decompression schedules for helium-oxygen were used; VER's at 16 cps were obtained during the 60-ft decompression stop. Since this decompression schedule is much slower than that used for the air runs, 17 minutes elapsed between leaving the bottom and arrival at the decompression stop.

RESULTS

The data from the main experiment, the dives on compressed air, consist of VER's to light flashing on and off either 2 or 16 times per second. These

two conditions yield very different responses. At the slower rate, the entire response to the stimulus, the striped pattern, is completed before the next light appears. The response is a complex waveform consisting of negative and positive components which last for at least several hundred milliseconds. At the faster rate, relatively simple sinusoidal-like responses result which show the same number of peaks as the rate of stimulus presentation. Advantages and disadvantages accrue to each rate: with rapid stimulus presentation the response is simple, easy to analyze, and individual differences are small but much of the waveform is lost; with the slow rate which does yield the complete response, there are large individual differences in waveform and evaluation of variations in components is difficult. A more detailed comparison of the VER's elicited by stimuli at different flash rates can be found in the work of Kinney, et al.[7,8]

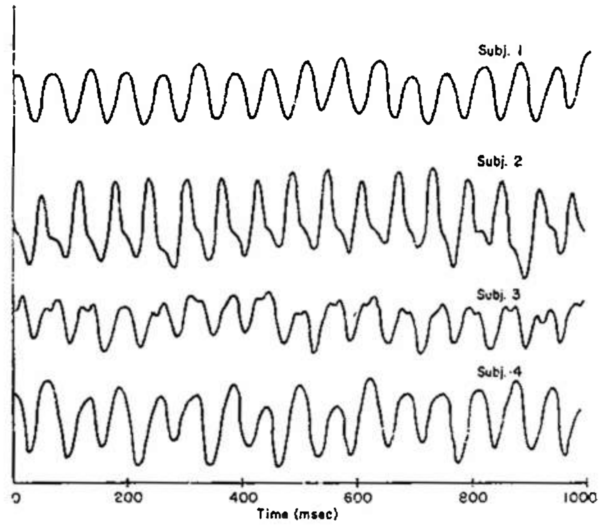

Fig. 1. Sample VER's for the 16 cps flash rate for the four divers at the surface.

Light Flashes at 16 cps

Typical VER's from each of the four subjects for the rapid stimulus rate are shown in Fig. 1. There are 16 inflections per second in the records from each subject. Differences in the waveform of the responses occur and are characteristic of each subject; nonetheless, these differences are minor compared to those that occur at the slower stimulus rate.

The data vary in two obvious dimensions: the amplitude of the 16 responses and their regularity. Calculations have therefore been made of the mean amplitude, peak to trough, and the standard deviation of the amplitudes, each based upon 16 measures. These data are given in Table I for each subject. Also shown are Z scores $(\frac{\overline{X} - 0}{\sigma})$, the ratios of the mean amplitude to the standard deviation, to indicate the regularity of the response compared to a theoretical mean of zero.

There are two major effects which occur at increasing depth: the mean amplitude of the responses decreases and the variability increases. The latter is sometimes apparent in an absolute increase in size of standard deviations; however, more commonly the sigmas of small mean amplitudes are likewise small and the Z score must be used to demonstrate the increased variability.

Figure 2 is an illustration of the changes, for the four divers at 250 ft, compared to the pre- and post-controls.

TABLE I - Means, Standard Deviations, and Z's ($\overline{X}/\sigma$) for VER's to 16 cps Flashes *

S	Run	Pre-Surface			Depth						Post-Surface		
		$\overline{X}$	σ	Z	$\overline{X}$	σ	Z	$\overline{X}$	σ	Z	$\overline{X}$	σ	Z
					100 Feet								
1	1	1.86	0.28	6.75	1.43	0.15	9.59				1.55	0.24	6.46
	2	2.92	0.57	5.14	2.99	0.47	6.32				2.57	0.82	3.15
2	1	1.78	0.65	2.75	1.25	0.44	2.85				2.95	0.53	5.55
	2	2.03	0.27	7.55	1.86	0.36	5.12				2.16	0.70	3.06
3	1	2.71	0.36	7.48	1.98	0.25	7.82				1.91	0.41	4.64
	2	1.11	0.33	3.38	0.96	0.49	1.96				2.04	0.75	2.71
4	1	2.18	1.16	1.88	2.81	0.77	3.63				2.31	0.61	3.81
	2	3.59	0.96	3.74	2.41	0.78	3.08				1.82	0.89	2.04
					200 Feet								
1	1	2.75	0.29	9.58	1.78	0.24	7.48				2.15	0.19	11.33
	2	2.25	0.20	11.25	1.40	0.28	5.07				1.85	0.87	2.12
2	1	1.86	0.61	3.06	1.50	0.42	3.56				1.64	0.43	3.85
	2	3.49	0.52	6.74	2.22	0.48	4.63				3.40	0.94	3.62
3	1	1.41	0.34	4.21	1.75	0.38	4.54				1.72	0.34	4.99
	2	0.82	0.21	3.86	0.96	0.33	2.88				1.49	0.25	5.84
4	1	3.01	1.11	2.72	1.57	0.83	1.90				2.12	0.63	3.35
	2	4.88	1.62	3.01	1.98	1.13	1.75				2.22	0.85	2.61
					250 Feet			70 Foot Stop					
1	1	1.84	0.24	7.59	0.49	0.10	4.89	0.76	0.20	3.78	2.12	0.20	10.87
	2	1.94	0.20	9.56	1.29	0.32	3.98	1.46	0.18	9.30	1.43	0.29	4.91
2	1	1.48	0.78	3.62	0.78	0.30	2.56	1.62	0.60	2.69	1.92	0.35	5.28
	2	4.15	0.33	12.59	2.46	0.51	4.81	2.69	0.54	4.95	4.66	0.56	8.34
3	1	1.13	0.32	3.56	0.87	0.33	2.61	1.04	0.23	4.50	1.18	0.29	4.07
	2	1.92	0.22	8.56	0.74	0.26	2.92	0.94	0.37	2.54	1.95	0.38	5.06
4	1	4.46	0.78	5.71	3.61	1.86	1.95	4.39	1.62	3.02	4.37	1.66	2.64
	2	3.73	0.46	8.17	2.09	0.76	2.73	2.68	1.28	2.09	2.50	0.63	3.98

* The two decimal place values given in the above table are rounded from calculations using four decimal places. As a result the Z scores given are exact and based on four decimal place divisions. This holds for all tables.

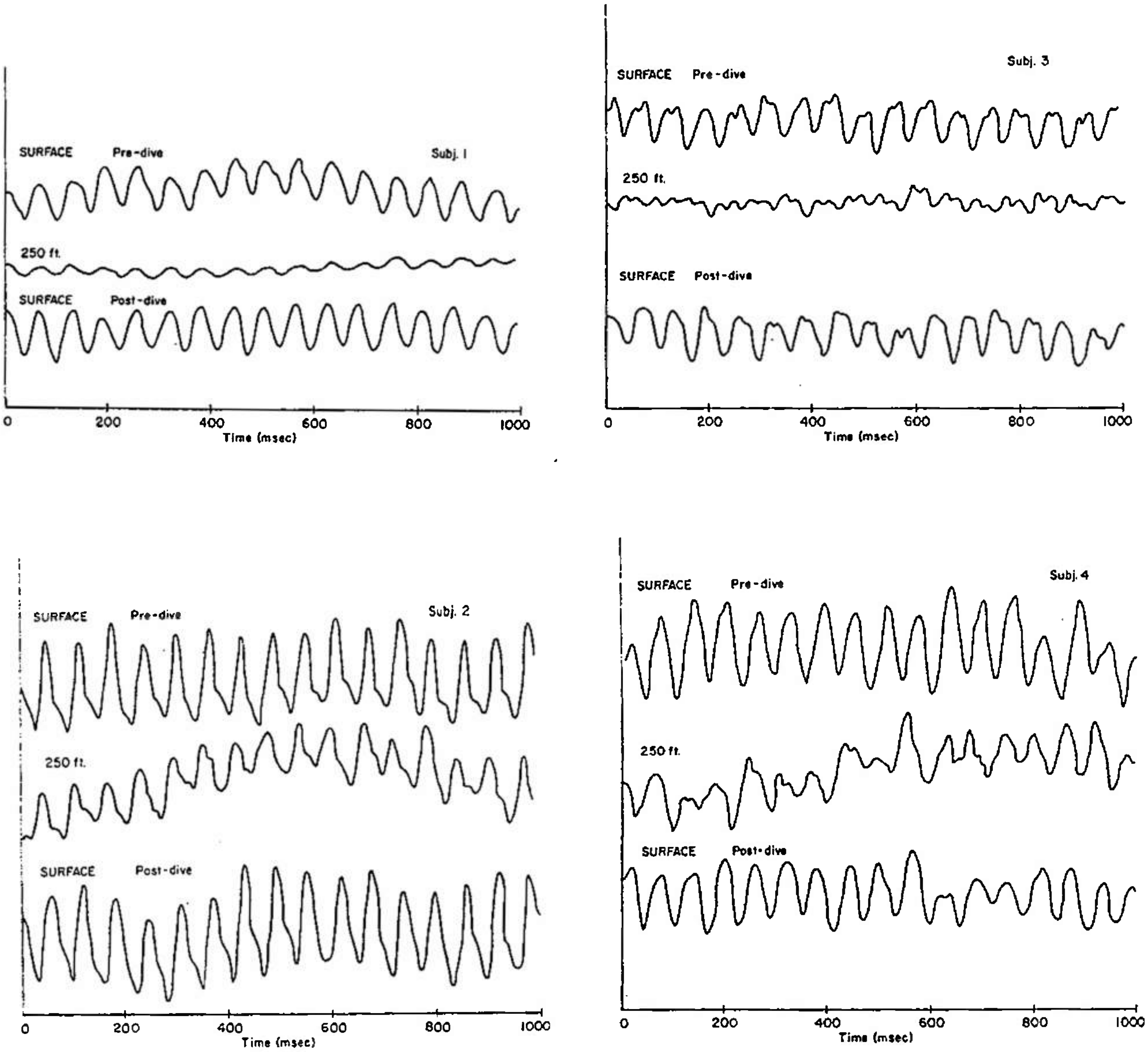

Fig. 2. Comparison of the surface controls and the VER's obtained at 250 ft in the same session for each diver. Flash rate is 16 cps.

The decreases in amplitude and in regularity of the VER are obvious in all divers. Occasionally the records were so irregular that 16 responses could not be identified; in these cases, the 1-second interval was divided into 16 equal time periods and the maximum amplitude in each taken as the measure.

The mean amplitude of the VER's for the two experimental sessions at each depth have been averaged in Table II. Relative amplitude, that is the ratio of the amplitude at depth to that of the pre-dive control at the surface, is also given. It should be noted that the post-surface control data are essentially the

TABLE II - Mean Amplitude and Z Scores of VER to 16 cps Flashes

S	Amplitude				Z Scores			
	Surface		Depth		Surface		Depth	
	Pre	Post			Pre	Post		
			100'				100'	
1	2.39	2.06	2.21		5.94	4.80	7.96	
2	1.90	2.56	1.56		5.15	4.30	3.98	
3	1.91	1.97	1.47		5.43	3.67	4.89	
4	2.88	2.06	2.61		2.81	2.92	3.35	
Mean	2.27	2.16	1.90		4.83	3.92	5.05	
Relative to Pre		.98	.86			.81	1.05	
			200'				200'	
1	2.50	2.18	1.59		10.42	6.72	6.28	
2	2.68	2.52	1.86		4.90	3.74	4.10	
3	1.12	1.60	1.36		1.12	1.60	1.36	
4	3.94	2.98	1.82		2.86	2.98	1.82	
Mean	2.56	2.32	1.66		4.82	3.76	3.39	
Relative to Pre		.95	.65			.78	.70	
			250'	70' stop			250'	70' stop
1	1.89	1.79	0.89	1.11	8.58	7.89	4.44	6.04
2	2.82	3.29	1.62	2.16	8.10	6.81	3.68	3.82
3	1.52	1.56	0.80	0.99	6.06	4.56	2.76	3.52
4	4.10	3.44	2.85	3.78	6.94	3.31	2.34	2.56
Mean	2.58	2.52	1.54	2.01	7.42	5.64	3.30	3.98
Relative to Pre		.99	.60	.78		.76	.44	.54

same as the pre-surface control data. The average relative amplitude of the VER's after the dive is .97 of its value before the dive. Analysis of variance of the relative amplitudes revealed that the differences among depths were significant at the .01 level.

The relative amplitude, averaged for the four divers, is plotted in Fig. 3 as a function of depth. There is a loss of response amplitude as depth is increased and some recovery is evident at the first decompression stop three minutes after leaving the bottom.

The relative Z scores are also plotted in Fig. 3, as a function of depth. These data show a sizeable increase in variability as a function of depth and again some recovery at the 70 ft decompression stop. It should be noted that the Z score does not simply reflect the same phenomenon as the amplitude score. If the 16 responses to light at depths were just as regular as they were at the surface, but reduced in amplitude, the Z score would be a straight line at unity. Instead the de-

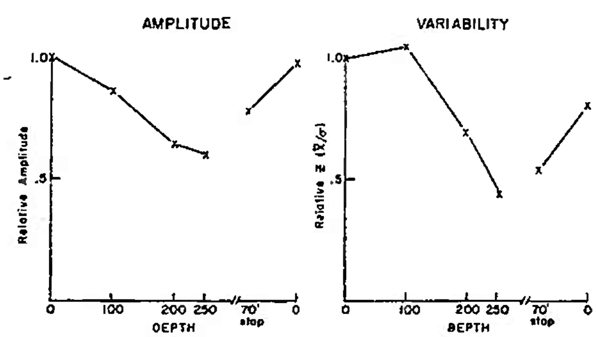

Fig. 3. Changes in amplitude (left) and variability (right) of the VER's to 16 cps flash rate as a function of depth.

crement is shown as an increase in variability compared to the size of the response. Unlike the amplitude scores, the Z scores do not show complete recovery for the post-surface control. This change will be discussed later in the section on control experiments.

Light Flashes at 2 cps

Figure 4 gives examples for each of the four subjects of the VER's that result from the two cps flash rate. Since the analysis time is one full second, two complete VER's are found. Individual differences in the number and location of various components are sizeable; nonetheless, each individual generally repeats his own characteristic waveform from one session to the next.

The simplest method of looking for differences in these VER's as a function of depth, is to overlay the responses obtained in a single experimental session. Examples of this type of analysis are shown in Fig. 5; one of the 250 ft dives is presented for each subject together with the pre- and post-surface controls. In each case, obviouse differences in waveform occur between the controls, which are generally alike, and the VER obtained at depth. It seems safe to assume that real differences in waveform do occur at depth, but the degree of the effect and its reliability need to be quantified. In order to do this, a technique of measuring the amplitude and latency of various components of the VER, worked out in a previous experiment,[7] has been employed.

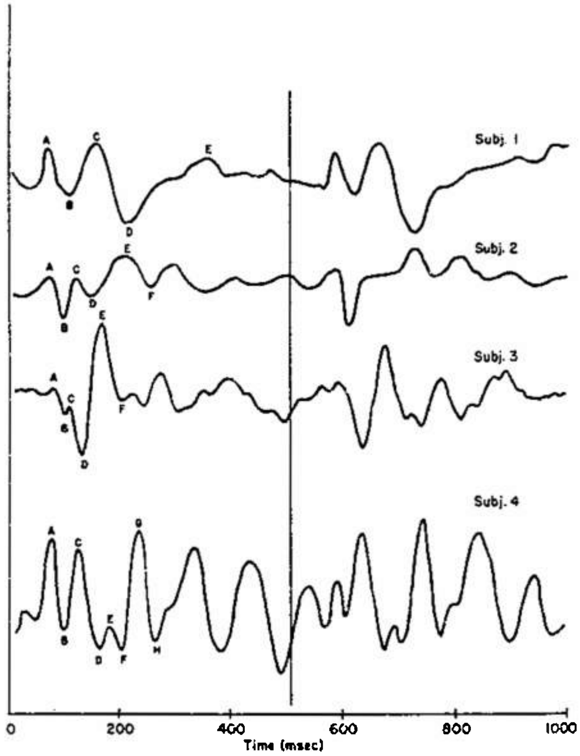

Fig. 4. *The VER's obtained at the surface for 2 cps flash rate for each diver. Major components used in the analysis are indicated by the capital letters.*

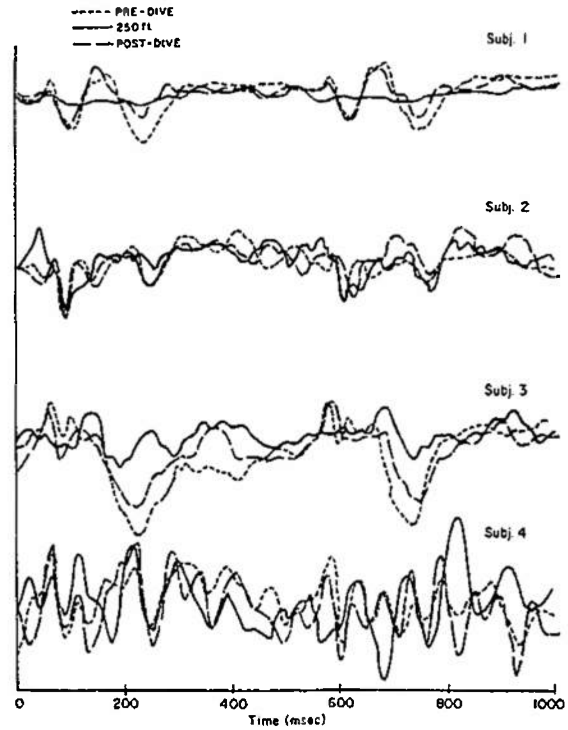

Fig. 5. *Comparison of the VER's obtained at 250 ft with the surface controls in the same session for the 2 cps flash rate.*

The first step in the analysis is to determine the major components for each subject by comparing the 10 surface control records. These components, indicated by capital letters, in Fig. 4, are not the same for different subjects; some, as Subject 1, have only a few inflections while others, as Subject 4, show a pattern of continual inversions. Components that occur later than 250-300 msec after the stimulus have been omitted from the analysis since they do not reflect the primary visual response.

The second step in the analysis is to measure the latencies of the various components and their amplitude. Since there are a sizeable number of records available at the surface for each subject, means and standard deviations of these values may be calculated. These data, $\overline{X}$'s and σ's of major components, are compiled in Tables III and IV. Also included in the tables are the amplitudes and latencies of the same components for each of the two runs at each depth.

TABLE III - Latencies of Major Components of VER's for 2 cps

Component	Surface				Depth		
	Pre-		Post-		100'	200'	250'
	$\bar{X}$	σ	$\bar{X}$	σ			
Subject 1							
A	65	4.5	64	3.7	63 64	70 67	63 73
B	106	4.9	102	4.0	110 104	110 105	113 110
C	152	13.3	144	8.0	170 132	140 145	155 153
D	213	10.8	208	11.7	230 206	208 200	229 205
E	342	13.3	320	26.1	290 338	332 355	345 270
Subject 2							
A	68	4.3	68	6.1	75 65	62 68	64 64
B	88	2.2	89	5.2	96 85	84 90	92 88
C	117	8.2	119	8.2	112 101	96 108	120 108
D	144	7.2	136	6.2	120 120	104 140	128 140
E	202	7.6	200	15.1	204 203	215 266	205 200
F	246	5.8	251	5.2	252 241	252 248	260 249
Subject 3							
A	63	2.9	65	7.2	70 72	64 64	40 56
B	84	2.2	85	7.8	90 00	88 82	76 72
C	99	3.9	107	11.7	98 102	96 98	92 88
D	131	9.2	129	7.2	116 116	118 114	115 106
E	161	7.7	158	9.6	160 152	154 146	140 148
F	211	8.2	216	13.4	196 206	194 220	188 192
Subject 4							
A	67	4.5	63	5.3	70 64	60 60	64 64
B	88	4.2	86	4.6	94 85	88 80	92 92
C	113	2.4	114	4.1	118 116	130 104	112 116
D	145	5.9	143	5.3	152 156	170 126	140 160
E	168	8.2	174	13.2	170 184	190 152	150 184
F	185	13.0	194	10.6	190 190	190 180	180 190
G	211	12.0	222	8.1	222 200	206 200	220 235
H	236	14.9	249	18.3	250 216	260 220	260 245

TABLE IV - Difference in Amplitude Between Components of VER's Obtained with 2 cps Flashes

Component	Surface				Depth		
	Pre-		Post-		100'	200'	250'
	$\bar{X}$	σ	$\bar{X}$	σ			
Subject 1							
A-B	+2.2	0.37	+2.2	1.38	+2.4 +4.5	+2.3 +2.4	+0.7 +3.1
B-C	-1.8	0.63	-1.6	1.17	-2.5 -1.9	-0.5 -1.0	-0.5 -1.1
C-D	+3.3	0.42	+3.5	1.46	+2.0 +2.9	+2.5 +1.5	+0.4 +2.3
D-E	-3.2	0.52	-3.3	1.10	-1.5 -5.0	-3.3 -3.7	-0.9 -1.7
Subject 2							
A-B	+2.4	0.52	+2.0	0.38	+1.2	+1.6 +1.5	+2.4 +1.3
B-C	-2.2	0.88	-2.0	0.37	-0.5	-0.8 -0.6	-1.4 0.0
C-D	+0.8	0.67	+0.3	0.37	+1.0	+0.6 +0.5	0.0 +1.3
D-E	-2.3	0.80	-1.9	0.51	-2.4	-2.2 -2.3	-1.5 -2.6
E-F	+2.0	0.55	+1.4	0.43	+0.8	+0.9 +1.0	+0.9 +2.1
Subject 3							
A-B	+1.3	0.44	+1.7	0.34	+1.1 +0.8	+1.8 +0.5	+0.2 +0.6
B-C	-0.6	0.38	-0.6	0.50	-0.2 0.0	-0.1 -0.3	-0.2 -0.2
C-D	+1.6	0.82	+0.6	0.52	+2.0 +0.8	+0.9 +0.4	+0.7 +0.4
D-E	-0.6	0.92	-0.6	0.74	-5.8 -2.5	-3.4 -0.9	-1.1 -1.7
E-F	+2.6	1.45	+2.9	0.77	+3.3 +4.5	+2.8 +2.2	+1.7 +2.8
Subject 4							
A-B	+2.3	1.30	+2.3	1.0	+2.8 +1.5	+1.4 +1.5	+1.7 +2.0
B-C	-3.4	1.02	-3.4	1.64	-3.1 -2.8	-1.8 -4.0	-2.7 -3.9
C-D	+3.9	1.72	+4.0	1.16	+2.7 +3.7	+2.9 +4.2	+2.0 +4.5
D-E	-1.6	0.78	-1.6	1.32	-0.7 -0.7	-1.7 -2.6	0.0 -1.1
E-F	+0.6	0.49	+0.9	0.59	+0.8 0.0	0.0 +2.2	+2.0 0.0
F-G	-2.1	1.65	-2.3	1.17	-2.3 -0.5	-1.3 -0.4	-4.4 -2.2
G-H	+2.3	1.40	+2.7	1.94	+2.4 +0.2	+2.0 +1.5	+3.8 +0.5

These data are depicted in Fig. 6 which shows, for each subject the average curve for the pre-surface control plus or minus one standard deviation as the shaded area around the average. The two VER's obtained at 250 ft are plotted on the same figure for comparison. There is no over-all loss in amplitude of the 2 cps VER with depth as there was in the 16 cps VER, except for Subject 1, nor is there any notable increase in variability. However, there are differences between some of the components in both amplitude and latency. For Subjects 1 and 2 the positive components around 120-150 msec are considerably reduced. For Subject 4 the positive component at 160 msec has been completely eliminated, while for Subject 3 a positive component has developed at 140 msec. These differences between the mean surface data and the VER at depth were generally consistent for each of the two runs at 200 ft also. Thus changes in the VER's between 100 and 200 msec occur for all subjects at depth; these changes however are not consistent among subjects.

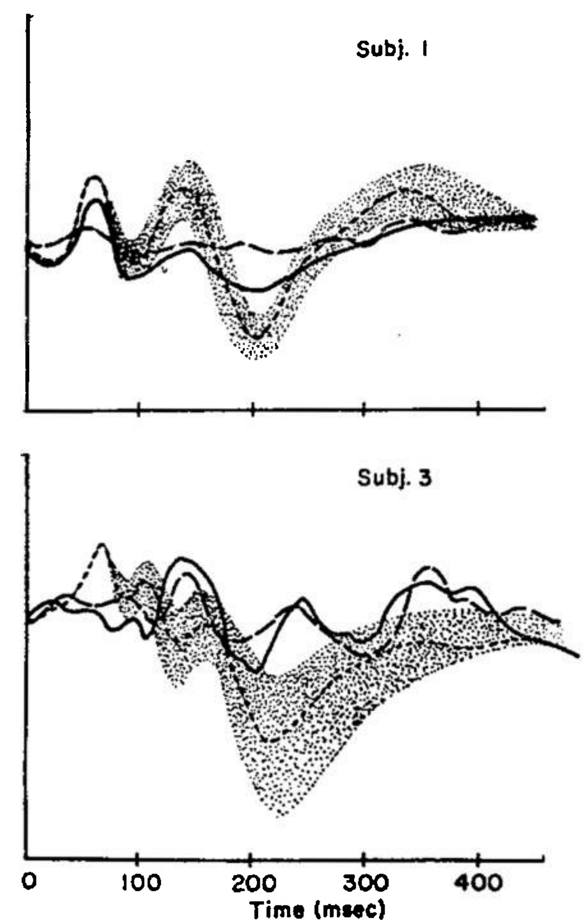

Fig. 6. The average 2 cps VER (——) for each diver at the surface computed from the mean amplitude and latency of the major components; the shaded area represents plus and minus one standard deviation around the mean. Also plotted, for comparison, are the VER's obtained during the two dives to 250 ft (—— and – –).

Analysis of variance of the components indicated there were no significant differences between the pre- and post-surface controls, either in terms of latency or of amplitude.

Results from Control Experiments

Temperature: A comparison of VER's obtained in a sauna operated at normal room temperature or at 37-39°C revealed no differences. The means, standard deviations, and Z scores for the four subjects are given in Table V. Visual comparison of the VER's for the 2 cps flash rate under the two temperature conditions likewise did not reveal differences.

Noise: Data obtained during the 10 ft dive with extensive noise are found in Table VI and Fig. 7. For the 16 cps flash rate there is some loss in mean amplitude; the average amplitude for the four divers at 10 ft is .89 of its pre-surface value. This average loss is due entirely to the data of Subject 1; two of the divers actually had a small increase in mean amplitude. The amplitude loss, therefore, is not considered significant.

On the other hand, there is a sizeable loss in Z scores; the data of all four subjects show increased variability at the 10 ft depth. In view of the fact that the Z scores for the post-surface controls do not show any recovery, further data would be required to resolve the question of whether the increase in variability evidenced in these VER's is indeed a result of the noise.

Figure 7 shows overlays of the 2 cps VER's for each diver; there are no differences in these curves which appear to be a function of the noise.

TABLE V - Comparison of Amplitude of VER's to 16 cps Flash Rate Taken at Different Temperatures

S	Normal Temperature			Sauna at 37-39°C		
	$\bar{X}$	σ	Z	$\bar{X}$	σ	Z
1	0.76	0.23	3.29	1.49	0.46	3.25
2	2.30	0.32	7.14	2.60	0.30	8.79
3	2.41	0.24	10.01	2.41	0.34	7.11
4	1.98	0.57	3.47	1.35	0.50	2.70
Mean	1.86	0.34	5.47	1.96	0.40	4.90

TABLE VI - Amplitude of VER's to 16 cps Flash Rate Obtained in Noise

S	Pre-Surface			Noise at 10'			Post-Surface		
	$\overline{X}$ ±	σ	Z	$\overline{X}$ ±	σ	Z	$\overline{X}$ ±	σ	Z
1	2.90	0.24	12.08	1.71	0.27	6.42	2.28	0.55	4.15
2	3.66	0.33	11.20	3.75	0.66	5.66	1.70	0.32	5.25
3	0.76	0.23	3.30	0.94	0.30	3.13	1.25	0.26	4.81
4	2.89	0.48	6.02	2.70	0.72	3.75	2.14	0.59	3.64
Mean	2.55		8.15	2.28		4.74	1.84		4.46
Relative to Pre-Surface				.89		.58	.72		.55

Time: Although there was no reason to believe that the amplitude of the VER's changed as a function of time during the dives, since the post-surface control after the 250 ft dive was .99 of the pre-surface control, the Z scores might have been affected, since they did not completely return to the pre-surface levels. However, analysis of five experimental sessions of 1-1/2 hours each, revealed no decrement in either amplitude or Z score over time. This variable can thus be discounted in the over-all results.

Nitrogen: Two dives to 250 ft were made by each subject breathing a helium-oxygen mixture; the mean amplitudes, standard deviations, and Z scores for the 16 cps VER's are given in Table VII and are summarized in Table VIII. Unfortunately, Subject 1 left the Navy before the helium-oxygen control was conducted. Data are available therefore on only three divers; for purposes of comparison Table VIII includes the mean values of the same three divers breathing air at 250 ft.

The mean amplitudes at 250 ft are .84 of their value in the pre-session control. The average Z score likewise is reduced to .85 of the control value. These decrements are not nearly so severe as they were for divers breathing air at 250 ft; in fact, for only 3

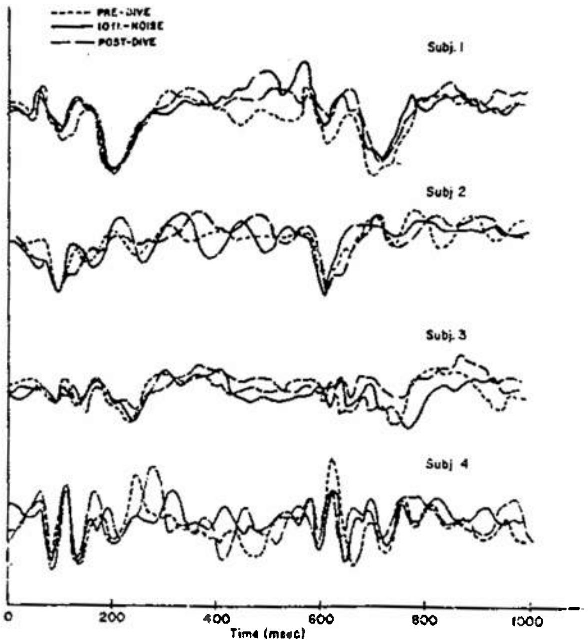

Fig. 7. Comparison of the 2 cps VER's obtained on the surface with the noise control for each diver.

divers this decrement of .84 is not significantly different from the surface value. It is possible however that small losses in amplitude and increases in variability do occur either as a function of depth, noise, or of the helium breathing mixture.

It should be noted that the amplitude of the post-surface control once again is .99 of the pre-surface level, even though approximately two hours intervened.

The VER's obtained at 250 ft for the 2 cps flash rate are overlaid in Fig. 8 on the pre- and post-session controls. The differences in waveform between 100 and 200 msec, found with air at 250 ft, are not apparent in these data obtained with helium-oxygen. In general, if there are differences among the three curves, the post-surface control is different while the pre-surface control and the data at 250 ft are the same.

DISCUSSION

The major result of this investigation is the demonstration of reliable and significant differences in visual evoked responses resulting from breathing compressed air at depth. Of the two measures employed, the VER to a 16 cps flash proved to be by far the easier to analyze. The mean amplitude of the 16 responses to the light decreased with depth, for each diver, while at the same time, the variability of the responses increased. The latter was sometimes so extensive that the following response to the 16 flashes disappeared from the VER completely.

Of the various controls performed, only the dive to 10 ft, with noise, and the helium-oxygen dive to 250 ft produced an effect on the VER's to 16 cycle flashes. Further study is necessary to assess its significance and to differentiate among the contributions of noise, pressure, and/or helium to this decrement. Nonetheless, all relevant factors are present in the 250 ft helium-oxygen dives. Since the only difference between these dives and the 250 ft dives on air is the breathing mixture, a direct comparison of the two should reveal the narcotic effect of nitrogen. This analysis shows the decrement found with helium oxygen to be of minor importance compared to that of air, for both the loss of amplitude and the increase in variability.

TABLE VII - Means, Standard Deviations, and Z Scores for VER's to 16 cps Flashes. Divers at 250 ft Breathing Helium-Oxygen

S	Run	Pre-Surface			Depth						Post-Surface		
		$\bar{X}$	σ	Z	$\bar{X}$	σ	Z	$\bar{X}$	σ	Z	$\bar{X}$	σ	Z
					250 Feet			60 Foot Stop					
2	1	3.35	0.42	8.05	2.06	0.73	2.82	3.11	0.95	3.26	4.34	0.73	5.97
	2	3.58	0.69	5.18	2.63	0.57	4.61	2.93	0.62	4.72	3.38	0.42	8.04
3	1	0.83	0.25	3.27	0.51	0.22	2.28	0.36	0.13	2.79	0.94	0.30	3.15
	2	1.30	0.31	4.19	1.18	0.22	5.36	1.31	0.26	5.03	1.25	0.37	3.37
4	1	2.78	0.63	4.39	1.92	0.79	2.45	2.23	0.79	2.82	3.04	0.94	3.25
	2	3.35	0.80	4.17	4.44	0.56	7.86	2.45	0.65	3.75	2.10	0.71	2.97

TABLE VIII - VER's to 16 cps Flash Rate Obtained at 250 Feet with Divers Breathing Helium-Oxygen

S	Amplitude				Z Scores			
	Surface		Depth		Surface		Depth	
	Pre $\bar{X} \pm \sigma$	Post $\bar{X} \pm \sigma$	250' $\bar{X} \pm \sigma$	60' Stop $\bar{X} \pm \sigma$	Pre $\bar{X}$	Post $\bar{X}$	250' $\bar{X}$	60' Stop $\bar{X}$
2	3.46 0.56	3.86 0.58	2.34 0.65	3.02 0.79	6.18	6.66	3.60	3.82
3	1.06 0.28	1.10 0.34	0.84 0.22	0.83 0.20	3.79	3.24	3.82	4.15
4	3.06 0.72	2.57 0.83	3.18 0.68	2.34 0.72	4.25	3.10	4.68	3.25
Mean	2.53	2.51	2.12	2.06	4.74	4.33	4.03	3.74
Relative to Pre-Surface		.99	.84	.81		.91	.85	.79
				70' Stop				
Mean of same 3 Ss on compressed air	2.81	2.76	1.76	2.31	7.03	4.89	2.93	3.30
Relative to Pre-Surface		.98	.63	.82		.70	.42	.47

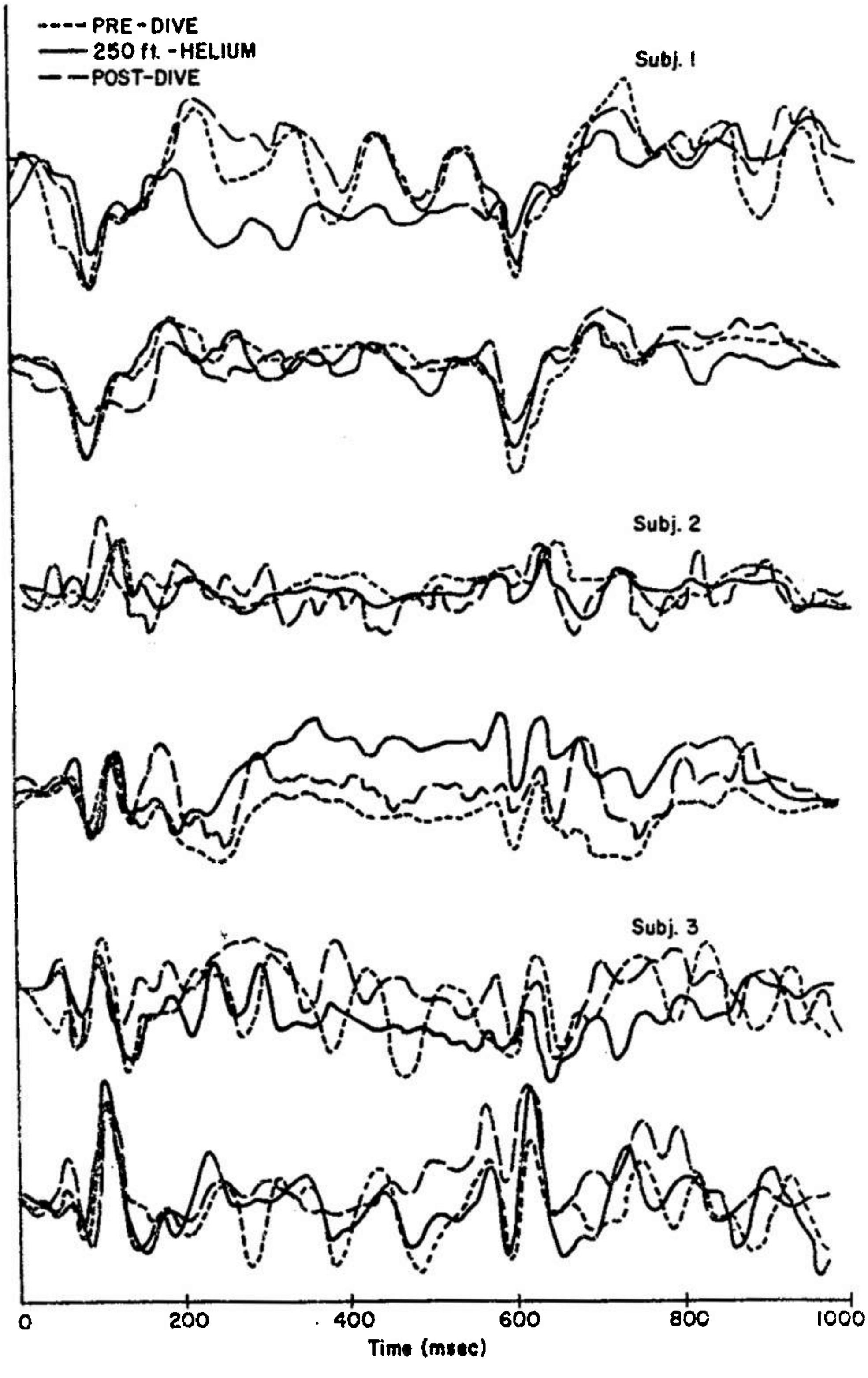

Fig. 8. Comparison of the VER's obtained on the 250 ft helium–oxygen dives with the surface controls.

The VER's obtained with the stimulus presented at a rate of 2 cps revealed differences between the surface controls and the deeper dives on compressed air. No comparable, consistent differences between surface and depth was found for the helium-oxygen dives nor for the other control experiments.

These data, for 2 cps, were further analyzed in terms of the latency and amplitude of major components in the waveform. These components were determined individually for each diver and comparisons made between the average surface control waveform and those obtained at depth. Differences in the waveform were found for all divers between 100 and 200 msec after the stimulus. The significance of this time interval cannot be specified, because the underlying mechanism of the VER is not yet understood. It is interesting to note, however, that this time period has been implicated in the response to patterned stimuli.[7,9] While decreased responsiveness to environmental details certainly could be a consequence of narcosis, further speculation on its mechanism must await more information on the etiology of the VER.

These data on the changes found in the VER were compared with performance data obtained on the same subjects breathing air at depth. There was general qualitative agreement between the two sets of data, in that both the behavioral and the electrophysiological data show an average decrement which increases as a function of depth. Quantitative comparison of individual's performance was not possible, however, due to variability in both sets of data. Considerably more data would be required to evaluate individual differences in susceptibility to nitrogen narcosis by either behavioral or electrophysiological techniques.

Similarly, more data would be required to correlate the electrophysiological response with subjective symptoms of narcosis. Typical exuberant behavior was exhibited by all divers on occasion and these incidents did appear to be accompanied by marked decrements in VER's. These experienced divers, however, did not show symptoms on every dive and many more dives would be required to statistically analyze the correspondence.

Another comparison is possible, this one with electrophysiological responses obtained by Bennett, Ackles, and Cripps[4] in a similar study of nitrogen narcosis. Bennett measured the auditory evoked response, for divers breathing air at depth and correlated this measure both with depth itself and with decrements in performance of arithmetic at depth. His stimulus was a click, presented once a second, and his measure the amplitude of response between components of the waveform at 90 and at 160 msec.

Despite the obvious differences between the auditory and the visual experiments, the two studies yield remarkably similar results. First, there is a decrement in the auditory evoked response which increases with depth and which correlates well with decrements in arithmetic. Second, a control dive to 300 ft with helium-oxygen yielded a 30% decrement in auditory evoked potential, a significant but con-

siderably smaller decrement than found when compressed air was employed. Finally, even the absolute sizes of losses at the various depths are comparable; our data (calculated in terms of the percent decrement in amplitude of the VER to 16 cps) fall on the same regression line relating % decrement to depth as do his. The puzzling fact that the stimulus rates that yield essentially the same results in the two experiments are so different may be resolved by the relative simplicity of the auditory evoked response pictured by Bennett; this response has so few components that it is perhaps more like our VER at 16 cps than at 2 cps.

Bennett considered the possibility that the decrement found with helium oxygen might be due to a synergistic action of oxygen; he consequently performed a control dive to 300 ft with decreased partial pressure of oxygen. The results showed no difference between this dive and normal mixtures of compressed air to the same depth thus discounting this explanation. Bennett believes oxygen itself reduces the evoked response; he did not, apparently, consider the effect of noise which might be expected to disrupt the auditory evoked response more than the visual. Another possibility is that the evoked response is so sensitive a measure that it is revealing a decrement attributable to an inert gas narcosis for helium. The reason for the small decrement in evoked responses, while breathing helium-oxygen, in both experiments thus remains obscure and certainly is worthy of further study.

Finally, the over-all agreement between this study of visual evoked response and Bennett's of auditory evoked response would seem to imply some fundamental underlying mechanism and attests to the feasibility of the evoked response to assess nitrogen narcosis.

SUMMARY

The visual evoked response of divers breathing air has revealed reliable and significant changes as a function of depth. Specifically, the amplitude of components between 100 and 200 milliseconds of the VER to 2 cps changed systematically, while both the amplitude and regularity of responses to high frequency flash rates decreased with depth.

These decrements are presumably attributable to the narcotic effects of nitrogen, because they did not appear in comparable dives when the divers were breathing helium-oxygen instead of air.

Control experiments eliminated the possible contribution of all other subsidiary factors from consideration with the possible exception of intense noise.

Comparisons with auditory evoked potentials and with behavioral data from other studies of nitrogen narcosis suggest the general feasibility and usefulness of the VER as a measure of narcosis.

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13. ABSTRACT
This study assesses the possible use of the visual evoked response as a measure of nitrogen narcosis in divers. Responses to a patterned visual target were recorded from the scalp over the occipital cortex, from divers breathing air in the NAVSUBMEDRSCHLAB's pressure chamber. Records were obtained at the surface, and at 100, 200, and 250 feet. Control dives to 250 ft with the same men breathing helium-oxygen were also performed. The results showed significant decreases in amplitude and regularity of the visual evoked response as a function of depth for divers breathing air but not comparable decrements with helium-oxygen.

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